

Letter to the Editor

Observation of Extended Red Emission (ERE) in the halo of M82 ^{*}

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Abstract. Low-dispersion spectra have been obtained from 4000 to 9600 Å along the axis and across the dusty halo of the galaxy M82. The spectra of the halo are explained in terms of scattering of the galactic light by dust grains: when divided by the spectrum of the galaxy, they reveal a broad emission band, similar to, although wider than the bump of Extended Red Emission (ERE) commonly observed in galactic reflection nebulae. The feature is particularly well marked in the filamentary parts of the halo.

This is the first detection of ERE outside of our Galaxy.

Key words: Scattering – Galaxies: halos – Galaxies: individual: M82

et al. 1988) or by fluorescence from solid state materials such as filmy Quenched Carbonaceous Composites (f-QCC) (Sakata et al. 1992) and Hydrogenated Amorphous Carbon (HAC) (Watanabe et al. 1982, Furton & Witt 1993). Although laboratory experiments on solid materials presently provide for the observed ERE a better fit than experiments on isolated molecules, no interpretation can be unambiguously established. Further laboratory studies as well as further observations of dusty objects are needed for a better understanding of the physico-chemical processes responsible for the ERE. In particular, the question about the universality of the ERE may arise. The galaxy M82 is a good candidate to attempt to answer this question because its halo might be considered as a giant reflection nebula (Schmidt et al. 1976) illuminated by the galaxy itself, which is seen approximately edge-on. It is thus easy to compare the spectrum of the galaxy to that of the light emitted by the halo. We have done such a study: this Letter describes our observations, and compare the results to those of analogous studies on galactic objects.

1. Introduction

The so-called Extended Red Emission (ERE) has been observed in the spectrum of various galactic objects: reflection nebulae (Witt & Boronson 1990), planetary nebulae (Furton & Witt 1992), HII regions (Sivan & Perrin 1993), the dark nebula L1780 (Mattila 1979, Chlewicki & Laureijs 1987) and high latitude cirrus (Guhathakurta & Tyson 1989). It consists of a broad emission bump about 1000 Å wide (FWHM), centered between 6500 and 7500 Å. The bump has been explained either by fluorescence from isolated molecules such as Polycyclic Aromatic Hydrocarbons (PAH) (d'Hendecourt et al. 1986, Léger

2. Observations and data reduction

Spectra of M82 were obtained in February 1995 using the Carelec long-slit spectrograph (Lemaître et al. 1990) equipped with a thinned back-illuminated Tektronix CCD, and mounted at the Cassegrain focus of the 193 cm telescope of the Observatoire de Haute Provence. Observations and data reduction were conducted following a procedure similar to that previously used for the study of HII regions (Perrin & Sivan 1992, Sivan & Perrin 1993). The spectral domain 4000 – 9600 Å was covered with a dispersion of 277 Å mm⁻¹. The slit width was 5".2, which corresponds to a resolution of 32 Å.

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^{*} Based on observations made at the Observatoire de Haute Provence du CNRS

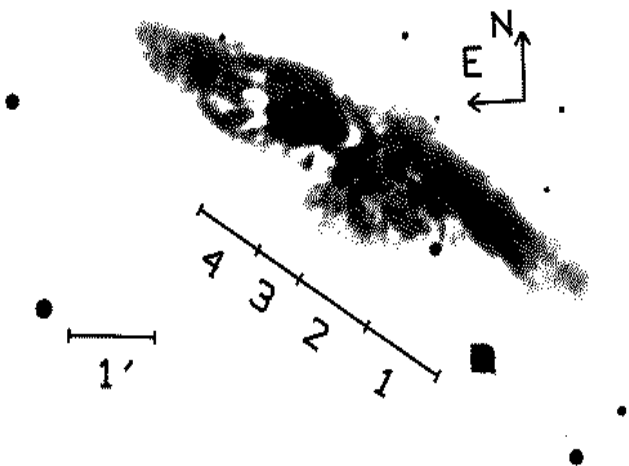


Fig. 1. The four regions observed spectrophotometrically in the halo of the galaxy M82, drawn on a photograph obtained with the 193cm telescope of the Observatoire de Haute Provence

Two parallel slit positions were observed, the first one along the axis of the galaxy and the second one across the halo, 100'' south-east (Fig. 1). In the latter case, we made a number of short exposures alternatively on the halo and on the surrounding sky background. This procedure permits a fine monitoring of the continuum spectrum of the night-sky background. After co-adding the short exposure frames, offset subtracting and flat fielding, the halo spectrum was spatially divided into four adjacent bins to separate the filaments present in the halo (regions 2, 3 and 4) from purely diffuse areas (region 1), as shown in Fig. 1. One-dimensional spectra were then extracted for each region. Sky subtraction was done by removing from halo spectra the corresponding sky background spectra extracted by binning the same pixels along the spectrograph slit (thus avoiding any instrumental effect). The same procedure was applied for the spectrum of the galaxy.

3. Results and Discussion

Figure 2 displays the spectrum of region 2 which corresponds to the most intense filament of the halo of M82. A strong continuum is observed with some superimposed emission lines such as $H\alpha$ and $H\beta$. According to Visvanathan & Sandage (1972) and Scarrot et al. (1991), the $H\alpha$ line is polarized and is at least partially due to scattering by grains of the line emitted by the nucleus of the galaxy. As the polarization is rather high, the atomic component in the observed continuum should be negligible. This is confirmed by theoretical calculations we have conducted for a pure hydrogen region and for a wide range of electronic temperatures ($5000 \leq T_e \leq 20000\text{K}$) and electronic densities ($100 \leq n_e \leq 10000 \text{ cm}^{-3}$): the atomic

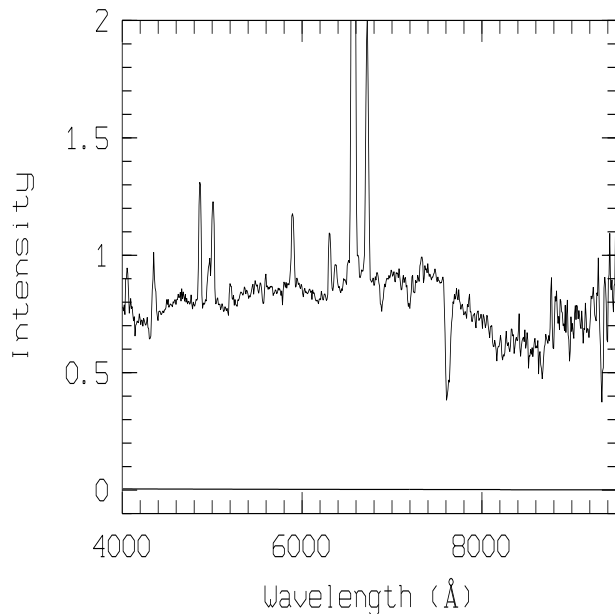


Fig. 2. The spectrum of region 2 (Fig. 1). The total integration time is of 100 minutes. Note the emission lines which are scattered lines from the galaxy and, close to zero level, the atomic continuum for hydrogen, calculated as explained in text. Ordinates are in units of $10^{-16} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1} \text{ arcsec}^{-2}$

continuum, when normalized to the observed $H\beta$ intensity, is found to be at the most four magnitudes lower than the observed continuum (Fig. 2). So, it is clear that the observed continuous spectrum of the halo of M82 should be regarded as essentially arising from scattering by grains of the light from the galaxy, a result in good agreement with that of Schmidt et al. (1976).

Assuming the same interstellar reddening for the galaxy and its halo, we have divided the spectra of the four regions considered in the halo by the spectrum of the galaxy. The resulting "spectra" are shown in Fig. 3: they appear to be typical of dust scattering spectra, with, except for region 1, a superimposed broad emission bump in the red, which, at first sight, looks like the ERE observed in galactic objects.

To isolate and characterize this bump, it is necessary to subtract the scattering continuum. This could be done by calculating a polynomial fit to the nebular spectrum divided by the galaxy, following the same method as that of Witt & Boroson (1990). We have preferred to fit a theoretical scattering spectrum calculated for a real material: HAC grains were chosen because they are a possible carrier of the ERE. Figure 4a shows one of the models best fitting the observed scattered component in the blue ($\lambda \lesssim 5000\text{Å}$) and in the red ($\lambda \gtrsim 9000\text{Å}$), two ranges where no fluorescence is supposed to occur.

After subtraction of the fitted scattering component, a broad red bump appears (Fig.4b). It is centered at about

6900 Å and is approximately 1500 Å wide (FWHM). This band thus appears to be markedly wider than the ERE observed in galactic objects that generally does not exceed 1000 Å in width. Its central wavelength is about the same as that observed in the reflection nebula NGC 2327 and in the planetary nebula NGC 7027, which means that the peak wavelength is on the high side of the range observed in these two categories of objects (Witt & Boroson 1990, Furton & Witt 1992). Comparison with galactic HII regions (Perrin & Sivan 1992, Sivan & Perrin 1993) shows that the ERE in M82 is bluer and, as in the previous cases, wider.

The ratio of ERE intensity to scattered light intensity, integrated from 5500 to 8500 Å is found to be the same for regions 2, 3 and 4 and is about 0.150 ± 0.005 . This value can be compared to those of Witt & Boroson (1990): it lies in the middle of the range observed for galactic reflection nebulae (if we except the Red Rectangle).

It should be noted that, of course, the fit to the observed continuum obtained in Fig. 4a, *does not rule out* other possibilities for the nature of the scattering material in the halo of M82. It is shown simply that a population of HAC grains might provide a possible common explanation for both luminescence and scattering, an interesting result that could not have been obtained by a simple analytical fit of the observed spectrum. We have also considered scattering by pure amorphous carbon grains, using the complex refractive indexes of Savvides (1986). No model was found to fit the observations: this is consistent with the above result, since pure amorphous carbon grains do not fluoresce in the red when irradiated by ultraviolet photons (Furton & Witt 1993).

would prove to be very useful.

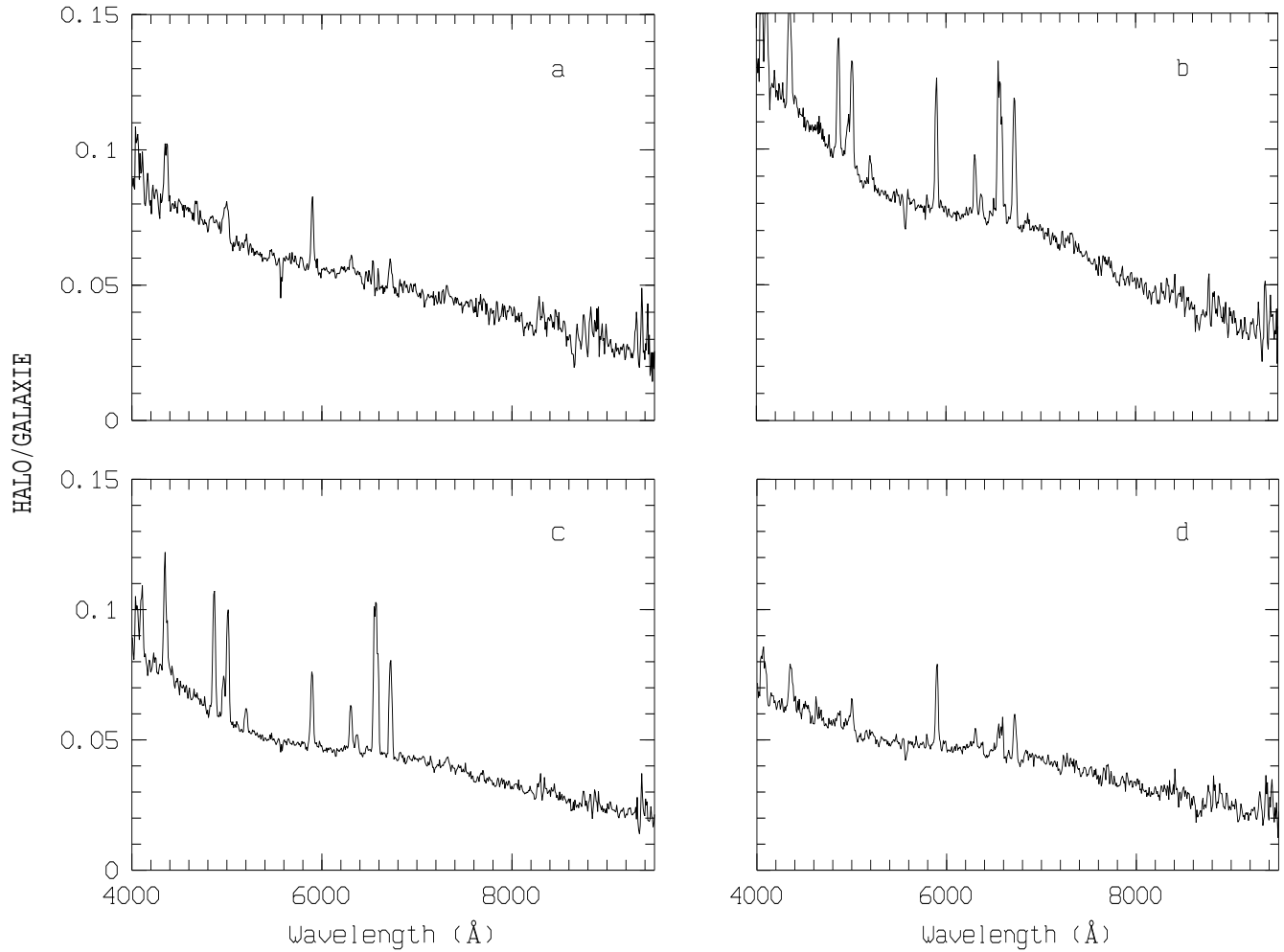


Fig. 3. Ratio of the spectrum of the halo of M82 to that of the galaxy, for regions 1 (a) and 3 (c) (Fig. 1)

Silicates have been identified in M82 (Gillet et al. 1975). Scattering spectra calculated using complex refractive indexes of extra-terrestrial silicates (Egan & Hilgeman 1979) provide a good fit to the observations. But the luminescence spectra of extra-terrestrial silicates is markedly different from the observed ERE (Derham & Geake 1964, Derham et al. 1964). Should organic ices and/or poly-HCN give rise to a luminescence band lookliking the ERE, silicate grains coated with these materials (Greenberg 1986) would explain completely our observations: we have verified that their scattering spectra also provide a good fit to the observed ones. Relevant laboratory studies on fluorescence from these materials induced by ultraviolet light

4. Conclusion

The observations reported in this Letter reveal for the first time the visible continuum spectrum of some regions in the dusty halo of the galaxy M82. In agreement with previous studies, it is interpreted in terms of scattering

by grains of the light from the galaxy disk. Superimposed over the scattering component, a broad emission band is found in the red, similar to, although wider than the ERE observed in galactic reflection nebulae.

This is the first detection of ERE outside of our Galaxy.

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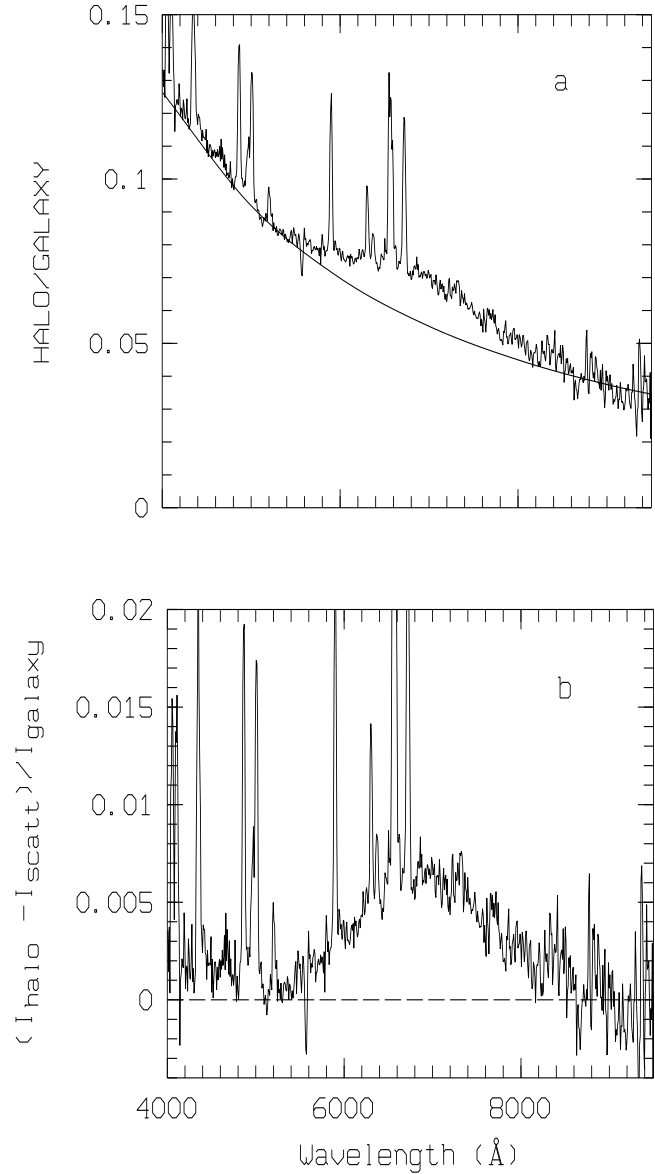


Fig. 4. **a:** Same figure as in Fig. 3b. The spectrum is well fitted in its bluer and redder parts by a scattering continuum spectrum calculated for homogeneous HAC particles, using complex indexes of refraction obtained by Khare et al. (1987) for HACs synthesized in experimental conditions similar to those of Furton & Witt (1993). **b:** The ERE obtained by subtracting the calculated scattering continuum from the observed spectrum